Decreasing Phosphorus Runoff Losses from Land-Applied Poultry Litter with Dietary Modifications and Alum Addition

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ABSTRACT

Phosphorus (P) losses from pastures fertilized with poultry litter contribute to the degradation of surface water quality in the United States. Dietary modification and manure amendments may reduce potential P runoff losses from pastures. In the current study, broilers were fed a normal diet, phytase diet, high available phosphorus (HAP) corn diet, or HAP corn + phytase diet. Litter treatments were untreated control and alum added at 10% by weight between flocks. Phytase and HAP corn diets reduced litter dissolved P content in poultry litter by 10 and 35%, respectively, compared with the normal diet (789 mg P kg^{-1}). Alum treatment of poultry litter reduced the amount of dissolved P by 47%, while a 74% reduction was noted after alum treatment of litter from the HAP corn + phytase diet. The P concentrations in runoff water were highest from plots receiving poultry litter from the normal diet, whereas plots receiving poultry litter from phytase and HAP corn diets had reduced P concentrations. The addition of alum to the various poultry litters reduced P runoff by 52 to 69%; the greatest reduction occurred when alum was used in conjunction with HAP corn and phytase. This study demonstrates the potential added benefits of using dietary modification in conjunction with manure amendments in poultry operations. Integrators and producers should consider the use of phytase, HAP corn, and alum to reduce potential P losses associated with poultry litter application to pastures.

THE GEOGRAPHIC CONCENTRATION of poultry operations often results in an influx of P in the region due to bird feed and the production of large amounts of P in poultry manure. Only a small percentage of this P source is potentially transported from the landscape to aquatic systems (Haggard et al., 2003), but this amount is often substantial enough to contribute to water quality problems, such as eutrophication and release of organic compounds from algae, such as geosmin and 2-methylisoborneol (MIB). The portion of P lost suggests a critical need to develop best management practices to reduce potential P losses from the landscape where poultry litter was applied.

Many best management practices have been studied to aid producers in reducing potential P losses where poultry litter is used as a fertilizer resource (Moore et al., 1999; Shreve et al., 1995; Moore and Miller, 1994).

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Alum [$(Al_2(SO_4)_3)\cdot 14H_2O$] applications to poultry litter have been shown to reduce P solubility by as much as 99% (Moore et al., 1999), while soluble P runoff losses from applications of poultry litter amended with alum may be reduced by as much as 87% (Shreve et al., 1995). Other manure amendments have reduced P solubility in poultry litter, but these amendments are not as physicochemically stable as the aluminum phosphates formed following the addition of alum (Moore and Miller, 1994).

Another potential best management practice is reducing the total amount of P in poultry feeds. Phosphorus supplementation is required in poultry rations, because most grains store between 80 and 90% of their P as phytate (Kornegay, 1996; Turner et al., 2002). Phytate-bound P is relatively stable, and not readily absorbed by poultry. Nutritionists therefore use supplemental P to adjust rations to meet dietary P requirements. Phytase is an enzyme that cleaves the P from the phytate molecule, and increases potential P bioavailability (Kies, 1996). The advantages of phytase supplementation in diets have been recognized for some time (Nelson et al., 1968; Nelson et al., 1971). High available phosphorus (HAP) corn are varieties that have been selected for their ability to store P in forms more bioavailable than phytate (Raboy, 2002).

Studies have shown that dietary modification treatments significantly reduce total P in litter, and may reduce litter soluble P. However, dietary modification with phytase may increase P runoff from pasture-applied litter (DeLaune et al., 2001) and also from land-applied swine manure (Smith et al., 2004b). In one study, a 100% increase in P concentrations in runoff occurred when phytase was used alone (DeLaune et al., 2001). It is likely that dietary modification may increase potential soluble P losses because the enzyme is used to solubilize P from an insoluble form, with the intent of increasing the amount of bioavailable P (for animal absorption) (Turner et al., 2002). Phytase does hold many other potential benefits, including increased availability of other nutrients, such as Ca and Zn, as well as reducing the P supplementation requirements in the diets (Kornegay et al., 1996).

The objectives of this study were to (i) compare the effects of dietary modification (phytase and HAP corn) and alum applications to poultry litter on P concentrations in litter and runoff waters and (ii) determine if diet modification and manure amendments combined could reduce P concentrations in runoff water.

MATERIALS AND METHODS

For this study, broiler production occurred in 32 pens with 55 birds per pen in each of three trials (Miles et al., 2003).

Abbreviations: DRP, dissolved reactive phosphorus; HAP, high available phosphorus.

Table 1. Ingredients and available and total P levels used for diets fed to broilers by phase.

	Phase 1 (Days 0–21)				Phase 2 (Days 21–42)			
Ingredient	Normal	Phytase	HAP† corn	HAP corn + phytase	Normal	Phytase	HAP corn	HAP corn + phytase
	%							
Normal corn	56.11	56.52			62.40	62.73		
HAP corn			52.90	53.29			58.53	59.22
Soybean meal	34.65	34.57	36.32	36.25	29.61	29.54	31.47	31.40
Poultry fat	4.73	4.58	6.46	6.33	3.99	3.91	5.92	5.78
Dicalcium phosphate	2.38	1.84	1.90	1.36	1.84	1.30	1.30	0.76
Limestone	1.09	1.40	1.37	1.68	1.14	1.45	1.46	1.77
Other	1.03	1.03	1.05	1.04	1.02	1.02	1.03	1.03
Available P	0.45	0.35	0.45	0.35	0.35	0.25	0.35	0.25
Total P	0.82	0.72	0.72	0.62	0.70	0.60	0.60	0.50

† High available phosphorus.

There were four dietary modification treatments: (i) normal diet based on National Research Council (1994) available P (aP), (ii) phytase diet based on NRC aP minus 0.1%, (iii) HAP corn diet based on NRC aP, and (iv) HAP corn + phytase based on NRC minus 0.1% aP. A two-phase diet was used with the starter diet being fed the first three weeks of each trial, and the finisher diet was fed for the remainder of the trial (Table 1). The two litter treatments used for this study were control or alum treatment applied at a rate of 10% by weight between flocks. After the third flock, a 30-kg sample of litter was collected for chemical characterization and rainfall simulation studies.

Litter from the bulk sample was analyzed for dissolved and total P. Dissolved P was analyzed using a 1:10 (w/w) ratio of litter to deionized water. This solution was shaken for 2 h at 180 oscillations per minute, centrifuged at 9800 × *g*, and vacuum-filtered through a 0.45-μm membrane filter. An aliquot was acidified to pH 2 with concentrated HCl, and analyzed for dissolved reactive P using the ascorbic acid reduction method on an autoanalyzer. Litter total P was analyzed by digestion with 15.8 *M* HNO_3 and 30% H_2O_2 and measured using inductively coupled argon plasma (ICAP) spectrophotometry (Zarcinas et al., 1987).

Litter from the bulk sample was applied to plots cropped to tall fescue (*Festuca arundinacea* Schreb.) at a rate equivalent to 8.97 Mg ha^{-1}. The plots were established in 1998 on a Captina silt loam soil (fine-silty, siliceous, active, mesic Typic Fragiudult) with a 5% slope at the University of Arkansas main agricultural farm in Fayetteville. Litter treatments were applied to plots on an average soil test phosphorus (STP) of approximately 199 mg Mehlich-III P kg^{-1} soil (Table 2). On Days 1, 8, and 15 after litter application, rainfall simulations were conducted at a rate equivalent to 50 mm h^{-1}. Discrete samples were collected every 5 min for 30 min following the onset of continuous runoff. A flow-weighted composite sample was formed from the discrete samples from each plot. Runoff pH and electrical conductivity were measured on an aliquot of the composite sample. An aliquot of the composite sample was filtered through a 0.45-μm membrane filter, acidified to pH 2 with concentrated HCl, and analyzed for dissolved reactive phosphorus (DRP) using the methods described above. Total P and total metals were analyzed from unfiltered runoff samples after digestion with APHA Method 3030E with ICAP spectrophotometry (American Public Health Association, 1992).

Forage was harvested twice by cutting 1 m^2 to a height of 5 cm. The forage was weighed and a subsample was dried and ground using a Wiley mill to pass a 2-mm sieve. Ground forage was used for determination of total P using the HNO_3 digest procedure (Zarcinas et al., 1987). Phosphorus uptake was calculated from forage tissue P concentrations and forage yield.

Phosphorus concentrations in runoff were log-normally distributed. Therefore, these concentrations were logarithmically transformed. Since many runoff P concentrations were <1.0 mg P L^{-1}, the value 1 was added to all P concentrations before logarithmic transformation, so that all values obtained would be positive (Neter et al., 1996). Statistics were performed using analysis of variance (ANOVA) procedures in SAS, with means separated at the 0.05 level using Fisher's protected LSD (SAS Institute, 1985).

RESULTS AND DISCUSSION

Phosphorus Content in Poultry Litter

Litter total P was reduced by dietary modification treatments (phytase and HAP corn; Fig. 1A). Phytase and HAP corn reduced litter total P from an average of 14 200 mg P kg^{-1} litter for broilers fed the normal diet to 11 600 mg P kg^{-1} litter (18% reduction) for phytase-fed broilers and 11 100 mg P kg^{-1} litter (22% reduction) for broilers fed the HAP corn diet. A 39% reduction in the amount of total P in poultry litter was observed in pens fed the HAP corn + phytase diet compared with the normal diet. These results were surprising considering there was only a 24% (Phase 1) to 29% (Phase 2) reduction in total P in the HAP corn + phytase diet compared with the normal diet (Table 1). Greater reductions in total P excretion than the reductions in P inputs with dietary modification is a very significant finding. While the reasons for this are not fully understood or explained by this research, one explanation is that the use of both phytase and HAP corn in diets provides a ration in which the P is in the most available form to the animal, allowing for greater P uptake. These reductions are greater than those found by Moore et

Table 2. Mean and standard deviation for soil test P for the Captina silt loam plots by treatment.

Litter treatment	Diet treatment	Mean soil test P	Standard deviation
		mg kg^{-1} soil	
Control	normal	168	37
	phytase	130	32
	HAP† corn	254	194
	HAP corn + phytase	159	42
Alum	normal	157	15
	phytase	245	249
	HAP corn	253	28
	HAP corn + phytase	271	19
Unfertilized		154	53

† High available phosphorus.

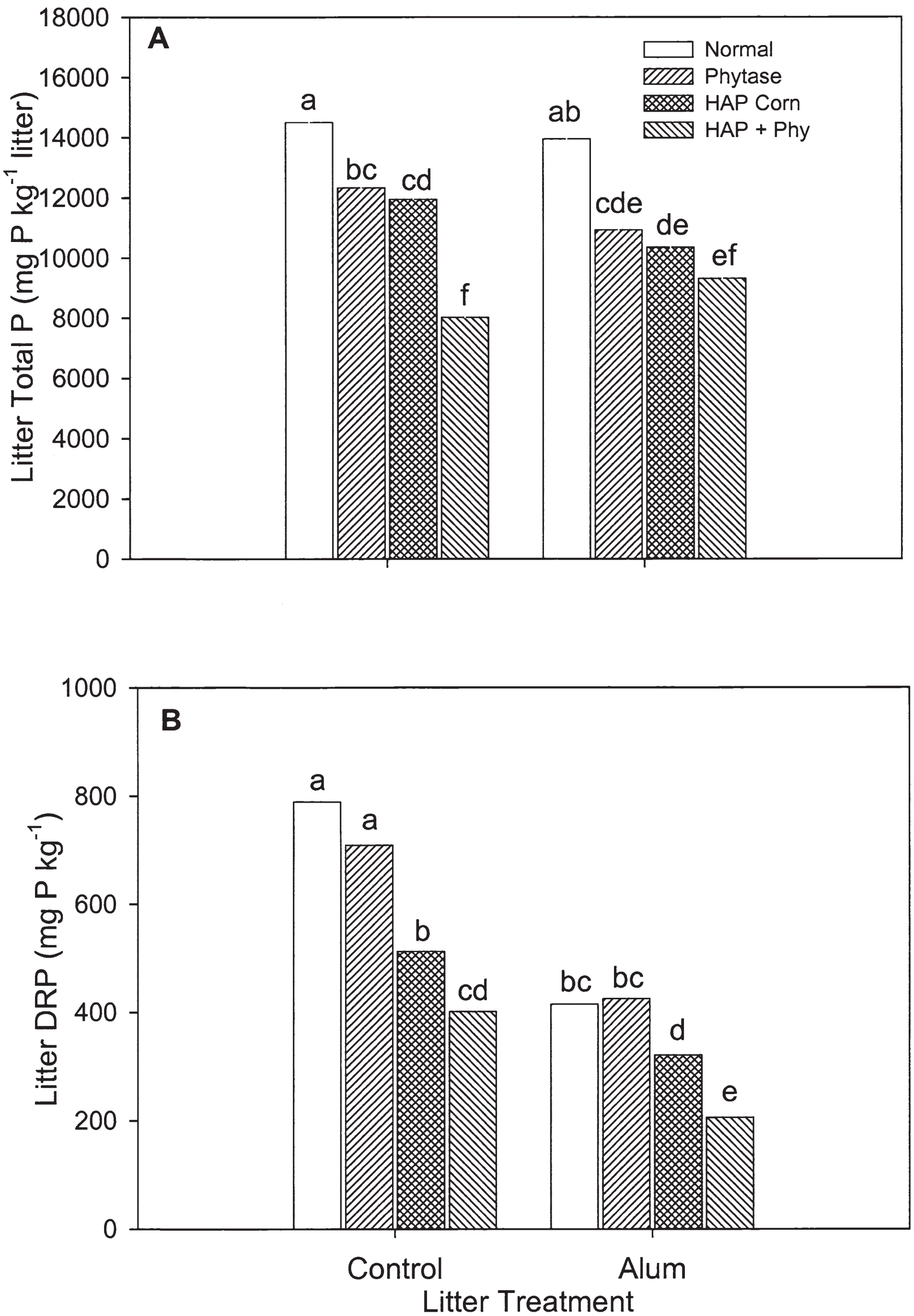

Fig. 1. Effect of dietary modification and alum litter treatment on (A) litter total P and (B) litter dissolved reactive phosphorus (DRP). Bars with different letters are significantly different at $P < 0.05$. Means separation performed using Fisher's protected LSD. HAP, high available phosphorus.

al. (1998), who found an 18% reduction in litter total P after two flocks of 42-d-old birds that were fed combination phytase and HAP corn diets. Our study, however, used a third flock, which may explain any discrepancy between these two studies. Litter treatment with alum did not significantly affect the total P in poultry litter within a given diet compared with the same diet without alum treatment. This result would be expected, because litter amendments are used to reduce soluble P, whereas dietary modification treatments are used to reduce the total amount of P fed to the animal and thus the total amount of P excreted by the animal.

The amount of DRP in poultry litter was reduced by dietary modification and alum treatment of the litter (Fig. 1B). Phytase alone reduced litter DRP 10% compared with the untreated control poultry litter, whereas HAP corn alone produced a 35% reduction in litter DRP. The combination of phytase and HAP corn resulted in a 49% reduction in litter DRP. These results are similar to a previous study that reported a 42%

reduction in litter soluble P when phytase and HAP corn were used together in broiler diets after two flocks of birds (Moore et al., 1998).

Normal and phytase diet poultry litter treated with alum had DRP levels similar to the untreated control litter (no alum) from birds fed the HAP corn and HAP corn + phytase diets; alum treatment of poultry litters reduced DRP content by 47%. These data suggest that using phytase and HAP corn may be as effective as using alum treatment alone to reduce litter DRP content. Within a given diet treatment, alum-treated litter contained significantly less DRP compared with litter from the same diet treatment without alum additions, indicating that a synergy exists between dietary modification and manure amendment treatments. All three treatments (phytase, HAP corn, and alum) together reduced litter DRP to 206 mg P kg^{-1} litter, a 74% reduction compared with untreated control litter from a normal diet.

Phosphorus Concentrations in Runoff Water

The effect of dietary modification and litter treatment on the pH and electrical conductivity of runoff water was not substantial, although application of any poultry litter generally increased both pH and conductivity. However, P concentrations in runoff waters were significantly different among treatments of dietary modification and alum. Runoff DRP concentrations were reduced by both dietary modification and litter treatment with alum (Fig. 2). Phosphorus reductions in runoff water resulting from dietary modification or alum treatments were greatest during the first rainfall simulation (Fig. 2A). All three dietary modification treatments (phytase, HAP corn, and HAP corn + phytase) without alum reduced runoff water DRP concentrations by approximately 45% compared with plots fertilized with normal diet litter without alum. These results contradict three previous studies that reported either no significant difference (Smith et al., 2004b; Moore et al., 1998) or significant increases in P runoff by as much as 100% due to incorporation of phytase into diets (DeLaune et al., 2001).

Incorporating alum with litter reduced P runoff from 18.2 mg P L^{-1} in runoff water from plots fertilized with the normal diet without alum litter to 7.2 mg P L^{-1} during the first rainfall event. When combined with alum, HAP corn, and HAP corn + phytase diets resulted in 68 and 69% reductions for P concentrations in runoff water compared with the normal diet without alum. As with litter DRP values, DRP in runoff water was slightly elevated from plots fertilized with the phytase diet alum-treated litter compared with the normal diet alum-treated litter; however, this trend was not significant. Within a given diet treatment, alum tended to reduce DRP concentrations in runoff water when compared with litter from birds fed the same diet but not receiving alum, but the difference was only statistically significant for the normal and HAP corn diets. These reductions resulting from alum application were as great as 60% for the normal diet and 43% for the HAP corn diet. During the first rainfall event, runoff DRP levels from all plots that received litter applications were statistically higher than the unfertilized control plot. This observation is in agreement with other studies that found that applications of P fertilizer or manure overwhelm P losses associated primarily with soil test P levels, thereby significantly increasing P concentrations in runoff water (DeLaune and Moore, 2001; Smith et al., 2004a, 2004b).

Data from the first rainfall simulation following manure application are important, because they indicate what may occur in a worst case scenario, where a runoff event occurs immediately following litter application. Results of the first rainfall simulation in this study indicate that any of these best management practices can significantly reduce P losses to surface water bodies compared with normal diet litter without alum treatment. It is also important to note that when best management practices were paired, particularly diet treatments with alum, there were generally marked reductions in runoff water DRP concentrations. Similar results have been noted for swine manure treated with phytase and aluminum chloride (Smith et al., 2004b). In addition, combinations of these best management practices may reduce other environmental or nuisance problems, such as NH_3 volatilization (Moore et al., 1999; Smith et al., 2004a). Litter applications also affect runoff water quality for some time following litter application (DeLaune and Moore, 2001).

Results from the second and third rainfall simulation studies were similar to the first; however, the magnitude of the differences was not as great for the latter events when compared with the first event. When comparing mean DRP content of runoff water from all three rainfall events, the only significant reductions tended to be between alum and no-alum treatments (Fig. 2B). There were no significant differences between mean DRP concentrations between diets within a given alum treatment. Alum alone reduced overall DRP levels in runoff waters from 5.6 mg P L^{-1} for the normal diet without alum treatment to 2.75 mg P L^{-1}, while there were 58 and 61% reductions with HAP corn diets with alum and HAP corn + phytase with alum. Runoff water DRP levels from plots receiving litter containing HAP corn and alum were not statistically different from unfertilized control plots when comparing the means from all three runoff events.

The variation in total P concentrations in runoff waters between treatments was very similar to that observed in the soluble P fraction. The greatest reduction in total P loss occurred when alum was used with phytase and HAP corn, although the reduction was not as great as that observed in the soluble fraction. The soluble fraction dominated total P loss from the small plots accounting for 96% of total P ($y = 0.96X - 0.47$; $R^2 = 0.98$). These data are consistent with results from Edwards and Daniel (1992), where approximately 80 to 90% of the total P was in the soluble form, and many other plot studies show similar results.

Several factors were investigated to see if they were related to P concentration in runoff water from small plots, including litter dissolved P, litter total P, soil test P, and runoff pH. The amount of dissolved P in the poultry litter explained the greatest amount of variation in runoff DRP concentrations ($R^2 = 0.72$). Soil test P had little effect on runoff DRP concentration when poultry litter was applied, which is consistent with other studies (DeLaune and Moore, 2001; Smith et al., 2004a, 2004b). This was most likely because the P loss in runoff water was overwhelmed by the amount of P surface-applied in litter. Interestingly, pH of runoff waters explained a greater portion of the variability in runoff DRP concentration than soil test P in plots or total P in the litter applied to plots. The greatest effect on runoff total P concentrations was also due to litter DRP (Table 3). Since runoff DRP and runoff total P were strongly correlated, this would be expected; however, there was a slight reduction in the correlation coefficient. Soil test P accounted for 14% of the variation in total P concentrations in runoff waters. This indicates that the differences in total and dissolved P in runoff could be due to the small amount of particulate losses. Sediment loss in runoff from all plots was minimal, indicating that the

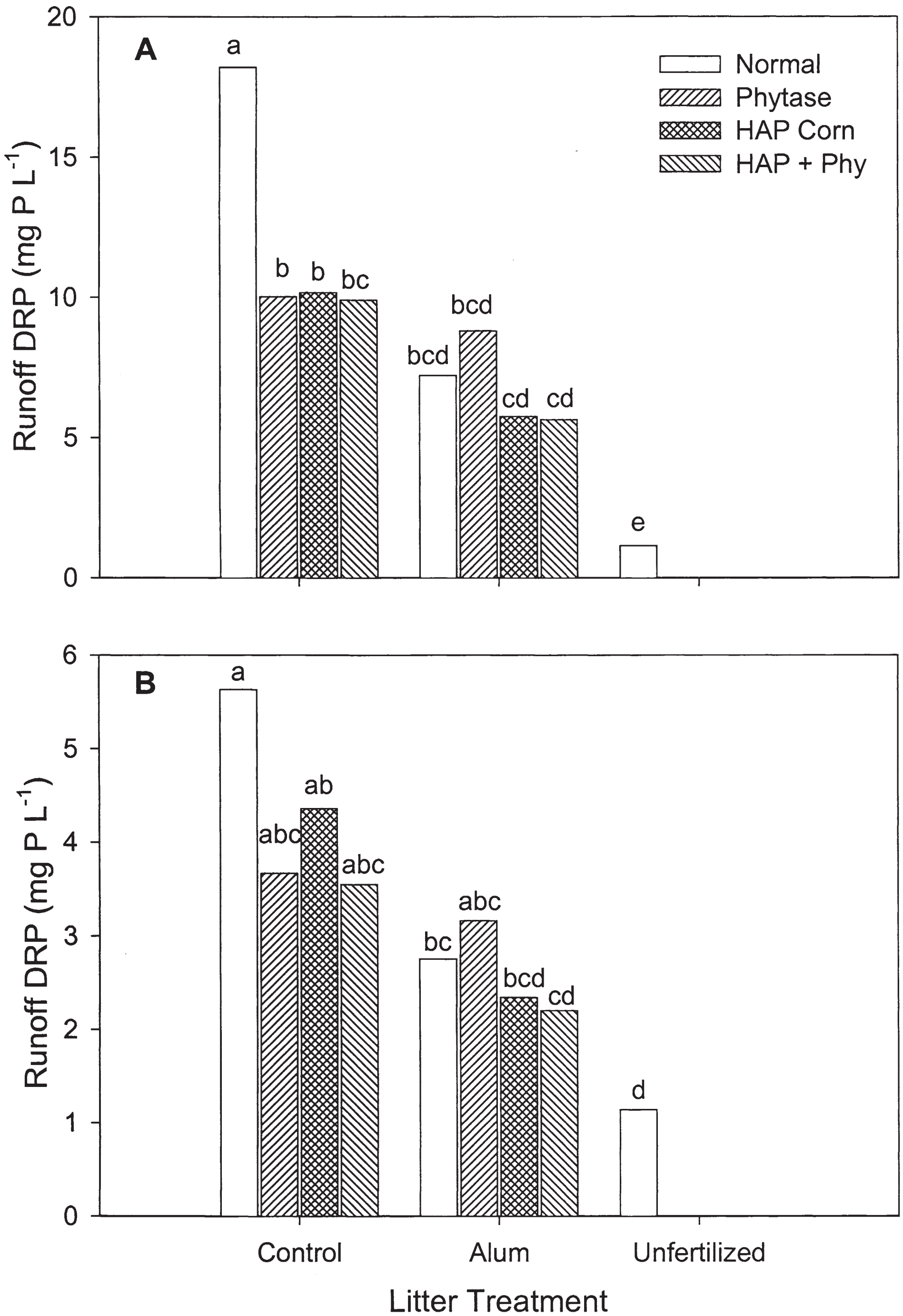

Fig. 2. Dissolved reactive phosphorus (DRP) from (A) the first runoff event and (B) the mean of all three runoff events resulting from application of poultry litter treated with dietary modification and/or alum additions to litter. Bars with different letters are significantly different at $P < 0.05$. Means separation performed using Fisher's protected LSD. HAP, high available phosphorus.

bulk of total P not in the soluble form was probably from an organic source.

Forage Yield and Phosphorus Uptake

Significant interactions were not noted for forage and P uptake data. These data are therefore presented by treatment main effect. Phosphorus concentrations in forage were higher in plots fertilized with litter containing no alum (5.9 g P kg^{-1} dry matter for the first harvest and 7.1 g P kg^{-1} dry matter for the second harvest) compared with plots fertilized with alum-treated litter (5.1 g kg^{-1} dry matter for the first harvest and 6.2 g kg^{-1} dry matter for the second harvest; Table 4). Unfertilized plots contained the highest P levels in forage for both harvests. There were no significant differences between diet treatments for forage P concentration in either harvest. There appeared to be a trend of higher P concentrations in forage that yielded less total dry matter within a harvest. This may be a factor of less total biomass production resulting in less total C in biomass per unit area, thus concentrating the total amount of P in forage.

Fertilization with litter significantly increased forage yield compared with unfertilized plots (Table 4). Dry matter yields from both the first and second harvest were significantly higher in the plots fertilized with alum-treated litter than the litter without alum. Forage harvested from plots was at least four times higher from plots fertilized with poultry litter compared with unfertilized control plots. There were no significant differences in dry matter yield resulting from the diet treatments; however, there was a trend of single dietary modifications (phytase or HAP corn) reducing forage yield and the combination of these two treatments reducing forage yield slightly more than if only one dietary modification treatment was used.

Litter applications to plots significantly increased the total P uptake in forage compared with unfertilized plots. There was 19% more P removed from soil by the plots fertilized with normal diet litter than plots receiving HAP corn + phytase diet litter (2.2 kg ha^{-1} for normal diet and 1.86 kg ha^{-1} for HAP corn + phytase diet). The most likely culprit in the increased P uptake from this treatment is due to increased level of N fertilization from the normal diet litter, probably resulting in increased plant vigor.

Table 3. Regression equations and Pearson product-moment correlation coefficients for runoff dissolved reactive phosphorus (DRP) and runoff total phosphorus (TP).

Independent variable	Regression equation	R
	DRP	
Litter DRP (LDRP)	DRP = 0.0152LDRP + 2.79	0.55***
Litter TP (LTP)	DRP = 0.000616LTP + 2.93	0.28
Soil test P (STP)	DRP = 0.0159STP + 6.18	0.29
Runoff pH (RpH)	DRP = 11.3RpH − 75.7	0.46**
	TP	
Litter DRP (LDRP)	TP = 0.0157LDRP + 3.23	0.53**
Litter TP (LTP)	TP = 0.000663LTP + 3.07	0.28
Soil test P (STP)	TP = 0.0193STP + 6.18	0.33*
Runoff pH (RpH)	TP = 11.6RpH − 77.5	0.44**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

CONCLUSIONS

Dietary modification with phytase or HAP corn reduced litter total P by as much as 39%. Dissolved P in litter was reduced by phytase (10%), HAP corn (35%), and alum (47%). Synergy between all of these treatments existed when used together, as indicated by a reduction from 789 mg dissolved P kg^{-1} found in normal litter to 206 mg dissolved P kg^{-1} in litter from broilers fed the HAP corn + phytase diet with alum litter amendments.

During the first rainfall simulation, DRP was reduced by approximately 45% with phytase, HAP corn, and HAP corn + phytase. Litter treatment with alum and no dietary modification reduced P runoff by 60%, while use of all three treatments resulted in 5.6 mg P L^{-1} runoff, a 69% reduction. Dissolved P in poultry litter applied to plots was the most important factor in determining P runoff.

Forage dry matter yield and P uptake were significantly higher when litter was applied to plots cropped to tall fescue. Alum resulted in elevated dry matter yield but reduced P concentration in forage, resulting in

Table 4. Forage yield and total P uptake by forage resulting from poultry litter applications to plots cropped to tall fescue as affected by litter alum treatment and dietary modification treatments.†

				Harvest 1		Harvest 2		
Treatment	DRP applied	TP applied	TN applied	Forage P concentration	Dry matter yield	Forage P concentration	Dry matter yield	Total P uptake
	kg P ha^{-1}		kg N ha^{-1}	g P kg^{-1} DM	kg ha^{-1}	g P kg^{-1} DM	kg ha^{-1}	
				Litter treatment				
Control	5.41z‡	105z	216y	5.94y	101y	7.10y	202y	2.00z
Alum	3.07y	100z	251z	5.13x	122z	6.16x	237z	2.07z
Unfertilized	NA§	NA	NA	9.01z	25x	10.0z	56x	0.79y
				Diet treatment				
Normal	5.40a	127a	247a	5.45b	119a	6.47b	248a	2.22a
Phytase	5.09a	104b	240ab	5.40b	115a	6.43b	233ab	2.10ab
HAP corn	3.74b	104b	232ab	5.62b	109a	6.81b	208ab	1.96ab
HAP corn + phytase	2.73c	78c	215b	5.68b	104a	6.82b	188b	1.86b
Unfertilized	NA	NA	NA	9.01a	25b	10.0a	56c	0.79c

† DM, dry matter; DRP, dissolved reactive phosphorus; HAP, high available phosphorus; TN, total nitrogen; TP, total phosphorus.
‡ Means followed by the same letter within a column for either litter treatment or diet treatment are not significantly different $P < 0.05$. Means separation performed using Fisher's protected LSD.
§ Dissolved reactive P, total P, or total N were not applied to unfertilized plots.

numerically higher total P uptake. Utilization of dietary modification resulted in slightly reduced yield and P uptake levels. Fertilization with HAP corn + phytase diet litter resulted in significantly less total P uptake than fertilization with the normal diet.

Data from this study indicate that both dietary modification and manure amendments may be able to reduce potential losses of P from pastures where poultry litter is applied for fertilization. When used together, dietary manipulation with phytase and/or HAP corn and treatment of litter with alum can significantly reduce P lost in runoff waters. These treatments may help producers in watersheds where P losses have already caused problems associated with eutrophication. These treatments should be tested on a whole-farm or watershed scale basis to determine the effects on surface water quality and to ensure they are economically feasible. Furthermore, research needs to be conducted to adjust P levels in diets to balance animal productivity and environmental quality.

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